Monitoring Microbial Degradation of Chlorinated Solvents with Carbon Isotopes

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RESEARCH OBJECTIVES

Chlorinated solvents are common groundwater contaminants. Because of their high density (greater than water) and low solubility, they are extremely difficult to remove from groundwater using standard remedial techniques such as pump-and-treat. *In situ* bacterial degradation of these compounds represents one alternative solution to this problem. However, it is very difficult to verify that these processes are actually occurring. One promising technique for monitoring subsurface microbial activity is to measure the carbon isotopic compositions of the contaminants and their degradation byproducts. Because microbial degradation of organic compounds favors breaking bonds with ^{12}C rather than ^{13}C, the isotopic ratio of the substrates tends to become enriched in ^{13}C. As a result, with a good understanding of the magnitude of the shift in the carbon isotope ratios caused by a specific process, we can determine the degree of degradation that has occurred. The purpose of this research is to quantify the carbon isotopic fractionation caused by different biologic processes known to degrade chlorinated solvents.

APPROACH

We have concentrated our studies on bioremediation of chlorinated ethenes that include some of the most toxic and recalcitrant chlorinated solvents, including perchloroethylene (PCE), trichloroethylene (TCE), isomers of dichloroethylene (DCE), and vinyl chloride (VC). These compounds can be anaerobically degraded by reductive dechlorination (whereby chloride ions are stripped from the molecules, progressively converting the contaminants from PCE to TCE to DCE to VC to ethene). Some organisms are only capable of completing one of these steps, whereas others can do more than one. Under aerobic conditions, chlorinated ethenes can also be oxidized to nontoxic end products (chloride ions and carbon dioxide) by several different oxygenase-expressing cultures. Some of the oxygenase-catalyzed degradations are metabolic (yielding energy and carbon for cell growth), while others are co-metabolic (providing no energy to the cells). Most prior studies of carbon isotope fractionation during biodegradation of chlorinated ethenes have used mixed cultures enriched from field sites where degradation is suspected. However, the results of these studies are variable. We are performing a series of experiments with pure cultures to determine how organisms using different mechanisms fractionate carbon isotopes.

ACCOMPLISHMENTS

We have completed and published a study of carbon isotope fractionation during aerobic degradation of chlorinated ethenes. The observed shifts were small (<1‰) for degradation of all of our experiments except those with VC, which were as high as 6‰. A series of anaerobic experiments with pure cultures are currently in progress. The carbon isotopic fractionation effects we have observed for these experiments are much larger (15 to 33‰, depending on the organism and the substrate) than for aerobic processes.

SIGNIFICANCE OF FINDINGS

The results of our work demonstrate that there can be significant differences in the magnitude of carbon isotope fractionation during biodegradation of chlorinated ethylenes, depending on the organisms involved and the metabolic process utilized. These differences can be used to determine which organisms are present and active in the field. When coupled with microbial genetic studies, this will lead to a comprehensive understanding of intrinsic bioremediation processes occurring at field sites. This understanding can be used to guide efforts to enhance biodegradation of the chlorinated solvents, by adding nutrients or bacteria to the system, and to monitor the success of these efforts.

RELATED PUBLICATIONS

Chu, K.-H., S. Mahendra, D.L. Song, M.E. Conrad, and L. Alvarez-Cohen, Stable carbon isotope fractionation during aerobic biodegradation of chlorinated ethenes. Environ. Sci. Technol., 38, 3126–3130, 2004. Berkeley Lab Report LBNL-55658.

Song, D.L., M.E. Conrad, K.S. Sorenson and L. Alvarez-Cohen, Stable carbon isotope fractionation during enhanced in-situ bioremediation of trichloroethene. Environ. Sci. Technol. 36, 2262–2268, 2002. Berkeley Lab Report LBNL-50047.

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